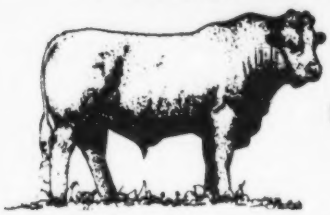
Ministry of Agriculture and Food
Ontario

PRINCIPLES OF GENETIC IMPROVEMENT IN BEEF PRODUCTION



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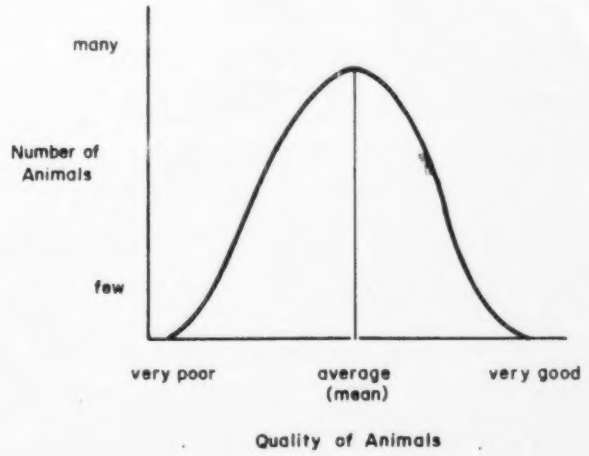
INTRODUCTION

Improvements in the genetic quality (genetic merit) of animals can contribute to the productivity, efficiency and profitability of any production system. Selective breeding of livestock is the method of improving genetic quality. The basic steps are: (1) identify traits which are important to the production system (define breeding goals); (2) identify animals which are of superior genetic merit for the traits of interest (genetic evaluation of animals); and (3) use the best animals as parents of the next generation (selection). The principles of genetic evaluation and selection are discussed below.

Figure 1. Normal Curve



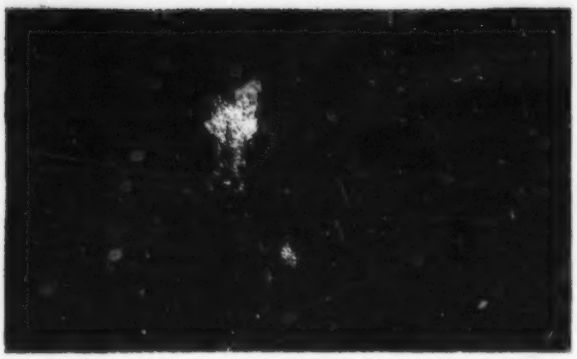
A normal curve can be used to show the distribution of animals for quality of phenotype or genotype. Most animals are near the mean of the population. Few animals are very good or very poor. Half (50%) of the animals are above the mean, and half are below. An animal may be in different positions on the genotype and phenotype curves. An individual could be very good on the genotype scale, but not perform well due to limiting environmental factors such as lack of feed. This animal would then be poor on the phenotype scale.

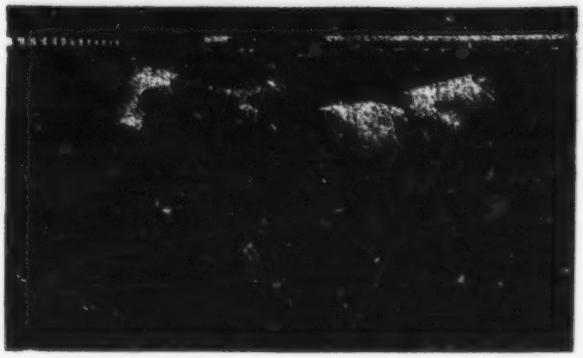
GENETICS AND ENVIRONMENT

All animals have characteristics of appearance and performance which can be observed or measured. There are many characteristics or **traits** which are important in beef production (e.g. milking ability, weaning weight, rate of gain). An animal's observed performance for a trait is its **phenotype**. Different animals can perform differently (have different phenotypes) for the same trait. For example, two animals could have weaning weights of 400 and 600 lbs. Variation in phenotype can be shown using a normal curve (Figure 1). A few animals are very good or very poor, but most are near the average or **mean** value for the population.

Where does this variation in phenotype come from? There are two main sources: genetics and environment. Consider two calves, each with a weaning weight of 500 lbs. The calves may have been raised in similar environments, and actually be similar in genetic blueprint or **genotype**. On the other hand, the first calf may have a good genotype but have been fed poorly, thus preventing it from growing to its full genetic potential. The second calf may have a poorer genotype, but have been well fed. The two calves could therefore have the same weaning weight despite their genetic differences. Observed weaning weight is clearly not a good indicator of genetic potential for weaning weight, when environments are different for the animals being compared. The formula: PHENOTYPE = GENOTYPE + ENVIRONMENT is commonly used to describe the relationship between observed performance, genetic merit, and environmental influences (Figures 2 and 3).

The overall environment affecting an animal is very complex. Feed, housing, weather and many other factors are important. Animals of a similar age which are kept together in a similar environment form a contemporary group. A contemporary group is sometimes called a management group. It is important to realize that if





Figures 2 and 3. Appearance is not generally a good indication of genetic merit because of the differing effects of environment. The bulls in Photo 1 are the same age and were reared together in the same environment. The animals in Figure 3, although as similar in size and weight as those in Figure 2, are of very different ages and were reared in very dissimilar environments.

groups of animals within a herd are treated differently, (eg. replacement heifers, first-calf heifers, show calves) then each of these is a different management group. Major environmental factors such as level of nutrition, housing, weather and health care are the same for all members of a contemporary group. Therefore, comparisons based on phenotype may be useful within such a group.

Factors such as milking and mothering ability of dam may differ for animals within a contemporary group. The milking and mothering ability of a cow are important traits in their own right. However, maternal differences between cows can be a complicating factor when evaluating calves for weaning weight. As a result of her maternal abilities, each cow contributes differently to the environment affecting her calf from birth to weaning. A good milker improves her calf's environment. The environmental contribution of a poor milker may restrict her calf's growth. Environmental differences within a contemporary group are generally less important than those environmental effects which differ between groups. Comparisons of animals in the same group based on phenotype, however, may be misleading due to environmental effects within that group. The use of more modern techniques of genetic evaluation will account for environmental effects between and within contemporary groups. The OMAF publication *Expected Progeny Differences for Beef Cattle* deals with these new evaluations.

Certain other factors can affect the measured performance of an animal. The age of a calf will affect many traits, for example, weaning weight. The age of the dam, and the sex of the calf will also cause variation in observed weaning weight. The adjustment of observed performance to remove the influence of such factors is common. For example, adjusted weaning weight is used to evaluate calves, and the dams of those calves. However, comparing cows on the basis of these adjusted weights can be affected by still other factors such as the sire of the calf. If two herdsires of different breeds were used in one herd, calf weights would be affected by sire breed. If two sires of the same breed, but of very different genetic value were used, the effect on cow evaluations would again be important. The new evaluation methods mentioned above will account for such factors.

HERITABILITY

Environment has a large effect on some traits such as temperament and fertility. It has a very small effect on other traits such as color. The color of cattle is genetically determined and is not affected by environmental conditions (Figure 4). The proportion of total (phenotypic) variation in a trait which is due to genetic differences between animals is the heritability.

Heritabilities range from 0 to 100%. If the heritability is high, the majority of phenotypic differences between animals are due to differences in genotype. Such a trait is not greatly affected by environment. The phenotype is therefore a better indication of genotype for a highly heritable trait than it is for traits with a low heritability. Heritabilities for some common traits are listed in Table 1. The heritability of a trait may not be the same for all populations. Cattle of different breeds or from different countries may have different heritabilities for the same trait.

Table 1. Approximate heritabilities of some common traits in beef cattle production.

	Heritability (%)
Low Heritability Traits (0-20%)	
Calving ease	10
Conception rate	5
Medium Heritability Traits (20-40%)	
Weaning weight	30
Milk yield	25
High Heritability Traits (40-100%)	
Average daily gain (post-weaning)	45
Finishing ability	50

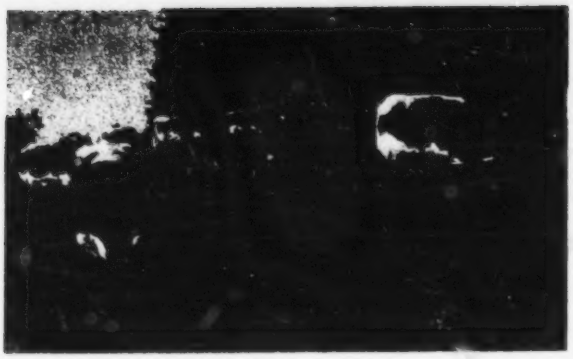


Figure 4. A trait where most of the variation in appearance or performance is due to genetic variation is highly heritable. The characteristic color pattern of the Pinzgauer cattle pictured here is a highly heritable trait.

PERFORMANCE PROGRAMS AND GENETIC EVALUATIONS

All animals do not have the same genetic quality. Variation in genotype, like variation in phenotype, follows a normal curve. The actual breeding value or genetic value of an animal cannot be measured directly. It must be estimated using performance information. Since most important traits in beef cattle have heritabilities of less than 50%, environmental factors must be considered when attempting to identify animals of superior breeding value.

Accurate, detailed performance records are required for the evaluation and comparison of animals. Many breed association and government performance programs currently collect such information. In an attempt to effectively compare animals on a genetic level, these programs do one of two things. They compare cattle only within contemporary groups or they try to reduce the effect of the environment on the observed performance of animals. Herd test programs use the first approach. Measured performance figures are adjusted for factors such as age and sex of calf, and age of dam. Nothing is done to account for the environmental differences between contemporary groups (ie. herds, or management groups within a herd). The data from these programs are therefore useful only when comparing animals from the same contemporary group.

Central test programs follow the second approach. Bull test programs are designed to compare bulls from different herds. The bulls are gathered in central locations, where they are all exposed to a similar environment. A one month adjustment period is used to allow the bulls to adjust to the new environment. This period also reduces the effects of the original herd environment on performance in the test station. Bulls are then compared based on their performance in the standardized station environment.

The figures reported by the various performance programs (eg. adjusted weaning weight, gain index) are used as indicators of genetic merit. In these programs not all effects of environment are accounted for or controlled. Therefore, the indicators of genetic merit are not ideal. The accuracy with which genetic merit is estimated (the agreement between the actual and estimated genetic merit) can be improved in several ways. Computer power allows us to examine records on all animals from all contemporary groups simultaneously. This information can be used to identify the overall effects of environment on any contemporary group. The estimation of genetic merit (breeding value) is therefore more accurate. Performance records on related individuals can be used to improve the evaluations. Measurements of related traits, on an individual or its relatives, can also be used. For example, when evaluating an animal for post-weaning gain, information on weaning weight can be useful since the two traits are genetically related.

The use of estimated breeding values (EBVs) and expected progeny differences (EPDs) calculated using all available information and the most advanced statistical techniques results in a major improvement in the accuracy of genetic evaluation. These statistics account for many of the present concerns (contemporary group effects, service sire effects, etc.).

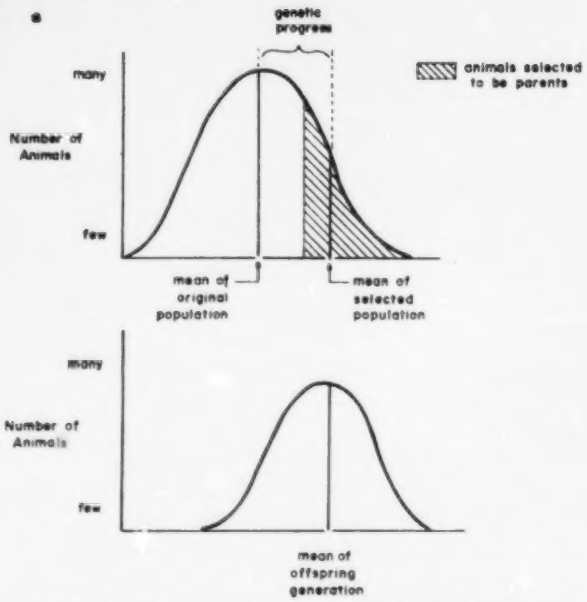
For successful genetic evaluation of animals, performance information must be complete and accurate. The unique identification of animals is essential. An animal's identification (eg. tattoo) must not be duplicated in its own herd, or in any other herd. The performance of an animal and its relatives, in all performance programs, can be used to improve the accuracy of evaluation. Animals must therefore be identified in the same manner in all performance programs. The sire and dam of each animal must also be carefully recorded so that all relatives can be identified. The correct coding of contemporary groups is also important. If animals which have been treated in different ways are coded as one contemporary group, the accuracy of evaluation will be greatly reduced. Furthermore, the size of a contemporary group can affect the degree to which the environment influencing that group can be accounted for. If only two show heifers are kept separate from the rest of the herd, evaluation of those heifers will be much less accurate than if 10 heifers had been grouped together. The two heifers may not be able to be evaluated at all. Guidelines of performance programs with regard to age restrictions, contemporary group sizes, sire representation, health requirements, etc. are necessary to allow the most accurate evaluation possible.

SELECTION AND RESPONSE TO SELECTION

To improve the overall genetic merit of a population for a given trait, only those animals with superior genotype should be chosen (selected) to be parents. An offspring receives half of its genetic information from each parent. The breeding value of the offspring is therefore determined by the parents' breeding values. Selection of above average parents will result in the next generation being better, on average, than the original population (Figure 5).

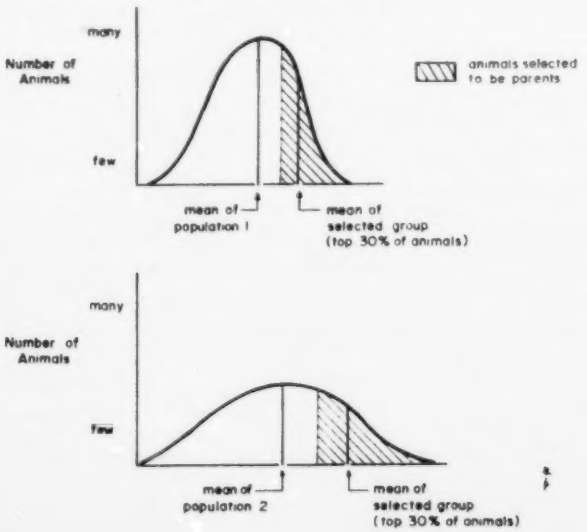
As a population responds to the forces of selection, the average genetic merit will improve. Genetic progress is measured as the change in the average breeding value of animals born each year. The rate of progress is affected by several factors. The amount of genetic variation present in the population affects genetic progress. If all

Figure 5. Selection



The animals with the best genotype should be selected as parents of the next generation. This selected group will have a mean higher than that of the overall population. The offspring of this group will have the same mean value as their parents. The mean has therefore been increased from one generation to the next. This is genetic progress.

Figure 6. Amount of Genetic Variation



Population 1 is more uniform in genotype for the trait of interest than is population 2. The animals are all closer to the mean. The genetic variation in population 1 is lower than that for population 2. Selecting the top 30% of animals from each population produces selected groups with different means. Due to the higher genetic variation in population 2, the mean of the selected group is higher. Therefore the rate of genetic progress will be faster in population 2 than in population 1.

animals were of the same genetic merit, there would be no variation. There would then be no "best" animals to select. Genetic improvement would therefore be impossible. As the range of genetic merit increases, the "best" animals are further above population average. Therefore, selecting the best animals as parents results in greater improvement of following generations when genetic variation is large (Figure 6).

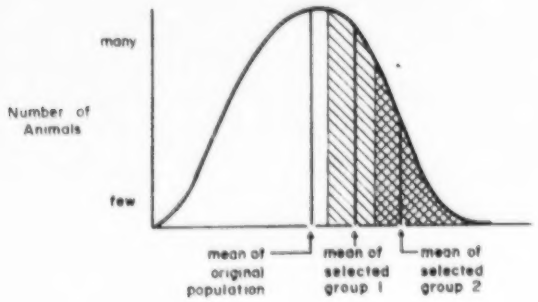
The accuracy of genetic evaluation affects the rate of genetic progress. If the accuracy is low, some of the animals selected for high estimated genetic merit may actually be inferior. The offspring of such animals will consequently be poorer than expected. The rate of genetic change in the population will be reduced. Accuracy is affected by the amount of information available for use in the evaluation, and by the heritability of the trait of interest. When more information is available (e.g. records on relatives and related traits), accuracy is increased. Heritability affects the amount of information required to produce an accurate evaluation. Generally, the higher the heritability, the higher the accuracy that can easily be achieved, since the complicating effects of the environment are relatively small. In other words, less information is required to produce an accurate evaluation for a trait of high heritability than for a trait of low heritability.

The average age of the animals in the breeding herd (generation interval) also affects the degree of genetic progress. Offspring are, on average, superior to their parents for genotype. Keeping an individual cow or bull in the breeding herd for many years will therefore reduce the rate of progress. That individual could have been replaced with a younger, better animal which would have increased the average genetic value of the parent population, and hence of subsequent generations.

The proportion of animals allowed to be parents will also affect the degree of progress. The group of best animals selected as parents have an average breeding value higher than that of the overall population. The minimum breeding value required for selection as a parent could be increased. This increases the selection intensity. Fewer animals would be able to meet the new standard for selection. Fewer parents would be selected, but the average breeding value of the new parent group would be higher than that of the original parent group. This leads to higher rates of genetic change (Figure 7). This is particularly important in male selection. A mature bull can service approximately 40 cows by natural service. The use of artificial insemination (AI) allows many more females to be mated to any one bull. Since few males are required for breeding, selection intensity can be much higher for males than for females. In populations where AI is common, the selection of less than 1% of males is sufficient.

The selection intensity for females (replacement heifers) in an average year is seldom less than 20%. Since the size of the calf crop depends on the number of breeding females, cows which are culled (removed) from the breeding herd for reproductive, structural or genetic reasons must be replaced. The number of replacements required depends on the culling rate. Increasing culling rate will lower the generation interval by increasing the number of young cows in the breeding herd. This will increase the rate of genetic progress. The need for more replacement heifers will decrease selection intensity of

Figure 7. Selection Intensity



Group 1 contains 40% of the animals available for selection while group 2 contains only 20%. The selection intensity is therefore higher for group 2. The mean of group 2 is higher than the mean of group 1. The offspring of the two groups will show this same difference in means. Therefore the degree of genetic progress will be greater if group 2 were selected to be parents than if group 1 were selected.

females, however, and the rate of progress will therefore decrease. A balance between selection intensity and generation interval must be maintained, based on individual herd requirements.

Selection for more than one trait (multiple trait selection) will generally reduce the rate of progress made for any one trait. Most producers are interested in improving more than one trait in their herd. It is therefore important to consider the genetic relationship between traits (genetic correlation). Traits can be positively correlated (when one trait increases, the other also increases). For example, birth weight and weaning weight are positively correlated. Traits can also be negatively correlated (when one trait increases, the other decreases). Birth weight and calving ease are negatively correlated. Selection for two traits will, as mentioned, reduce the rate of progress for each trait. The rate will not be greatly reduced if the two traits are positively correlated. A greater reduction will occur if the two traits are not correlated. If the traits are negatively correlated, the rate of progress is reduced even more. If two traits are positively correlated, selecting for an increase in the one and a decrease in the other has the same result on rate of progress as if they were negatively correlated. Such selection may be important to producers.

Selection for one important trait will cause changes in correlated traits, even if these traits have not been directly selected for. For example, selecting to increase weaning weight will result in increased birth weight. This may be a problem since higher birth weight is associated with calving difficulties. A producer may therefore wish to select for increased weaning weight and decreased birth weight. Progress for both traits will be slower, but calving problems will be minimized.

The maximum genetic change possible in one generation is small. Consequently, selection programs must be defined and applied over a long period of time to obtain appreciable genetic progress (Figures 8 and 9).

Figures 8 and 9. Selection based on genetic merit leads to genetic change. These pictures demonstrate the change in physical characteristics of typical Hereford cows due in part to 30 years of selection. The upper picture illustrates a typical old style Hereford, while the lower picture shows a modern cow.

OVERVIEW

As discussed in the introduction, there are three steps to genetic improvement: (a) definition of breeding goals, (b) genetic evaluation of animals, and (c) selection. To this point, evaluation and selection have been discussed in detail. The principles of evaluation and selection can be widely applied in many situations. In the definition of breeding goals, however, there are as many options as there are production systems. Since economic success is seldom defined in terms of only one trait, multiple trait selection is the usual approach. It is very important that each producer determine the traits of interest in his own production system, and the relative importance of those traits.

Genetic progress can enhance any production system for any type of livestock. The improvement of management skills must be stressed in all competitive operations.

However, the best management can only obtain that level of performance of which the livestock are genetically capable. Any management strategy will be more successful if the genetic merit of the livestock is improved.

Genetic improvement is not costly to undertake. Applying the techniques of selective breeding will result in observable genetic progress.

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